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Reliability Evaluation of Gaighat Radial Distribution Feeder with Distributed Generation Impacts

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Abstract

The power system especially at the distribution level is prone to failures and disturbances due to weather related issues and human errors so it is very important to plan and maintain reliable power systems because cost of interruptions and power outages can have severe economic impact on the utility and its customers. Having distributed generation (DG) as a backup source ensures the reliability of electric power supply. In this study, the value of DG installed as a backup generator is quantified in terms of its contribution to the reliability improvement of a residential distribution network. Distributed generation is that of limited size ($\leqslant$10MW) and interconnected at the substation, distribution feeder or customer load points. DG technologies include photo voltaics, wind turbines, small and micro sized turbine packages and IC engine generators. DG has some specific characteristics which distinguish it form conventional generating units to perform reliability evaluation. Therefore an appropriate modeling of DG is necessary to know the impact of DG on reliability of the distribution system. In this paper a reliability model for DG is developed, an analytical probabilistic approach is proposed and the primary reliability indices, load point indices and performance indices are calculated for each model. The reliability improvement is measured by reliability indices that include SAIFI, SAIDI, CAIDI, ASAI, ASUI and EENS. The reliability parameters of the Gaighat Radial feeder SAIFI, SAIDI, CAIDI, ASAI, ASUI and ENS without DG are found 7.7875 f/customer. Yr, 274.4490 hr/customer.yr, 35.242 hr/customer interruption, 0.9687 pu, 0.03133 pu and 1511.484 MW hr/yr respectively. The reliability of the feeder is then evaluated for different cases with DG varying location of the DG on the feeder.

Keywords

Distribution System, Distributed Generation, Reliability Indices

1. Introduction

Distributed generation (DG) is normally defined as small generation units (<10 MW) installed in distribution systems [1]. Distributed generation is expected to play an increasing role in emerging electric power systems. The spare or redundant capacities in generation and network facilities have been in built in order to ensure adequate and acceptable continuity of supply in the event of failure, forced outages of plant and removal of facilities in regular scheduled maintenance. Reliability elevation of electric power systems has been an integral part of planning and operation of electric power systems. They use different types of resources and technologies to serve energy to power systems. DG applications result in positive and negative side effects for both utility and customers [2].

Reduction of system expansion costs, decreasing loss of power and reliability enhancement are some of the benefits of DG applications. In contrast, power quality issues, islanding operation and voltage control problem are among troublesome impacts of DG on power system [3]. Utilizing a DG in power system should considerably improve reliability indices. Distributed generation can improve the utility's ability to serve peak load on a feeder, and thus allows deferral of capital investment on a feeder. DG helps to supply load during contingencies, until the utility can restore additional delivery capacity. DG has some specific characteristics which distinguish it from conventional generating units [4]. Therefore, they could not be treated neither as conventional generation nor substation to perform reliability evaluation. Nevertheless, special condition of DG is not considered and the DG is considered to play the same role as conventional generating stations or distribution substation. An analytical technique is presented in this paper to study the DG impact on the distribution system reliability. The paper is arranged as follows: next section broadly discusses the problem, its background and the requirement for an analytical model.

Main generating stations usually have two state models in which it can only toggle between up and down states. Another difference is the behavior of resources used in DG to produce the electric energy. For example, Renewable energy technologies have considerable contribution in DG technologies which use green energy resources such as wind and solar energy to produce power. Their output power depends on the amount of available resource at each moment. Therefore, compared with conventional stations, the power produced by renewable energy may experience more fluctuations. The case does not usually happened in the conventional generating stations and hence, this phenomenon is not usually included in the traditional reliability evaluation methods for generating stations.

Based on the above issues, applying traditional reliability models, such as generation station or distribution cannot properly reflect DG impact on the reliability and there is a need to develop suitable models. A model used to evaluate DG application must include different DG parameters and its intrinsic behavior. Once the model is developed, it can be used to compare different DG technologies from the reliability point of view. It could be applied in DG sizing and sitting problems and helps to include DG impact in different optimization problems, such as distribution planning, operation planning and switching placement. Broadly speaking, the method would be used in any normative application. In fact, this is the main advantage of analytical analysis of reliability indices over the computer simulation. The method is also unifies DG modeling in traditional distribution system reliability analysis frame work. This unification allows application of reliability enhancement method and practices in DG installation problem.

This thesis presents a new methodology to simulate power distribution system with DG and to compute the reliability indices. The proposed method uses an Electrical Transient and Analysis Program (ETAP), software is the main tool used for the simulation. ETAP is the most comprehensive analysis platform for the design, simulation, operation, control, optimization, and automation of generation, transmission, distribution, and industrial power systems. Inside the ETAP simulator, we have different simulators like Load Flow Analysis, Transient Stability Analysis, Optimal Power Flow, Optimal Capacitor Placement, and Reliability Analysis and Short Circuit

2. Methodology

2.1 Literature Review

The main focus of this study is on the availability of a reliable and economic supply of electric energy to their customers by studing various literatures which have discussed how the reliability impact of various applications of DG can be modeled in commercially available software tools.

2.2 Data Collection

2.3 Case Study

Reliability Evaluation of Gaighat Radial Distribution Feeder with Distributed Generation Impacts.

2.4 Distribution System Relibilability Evaluation

This section briefly discusses reliability evaluation techniques applied in distribution system. A sample distribution test system is shown in Figure 1

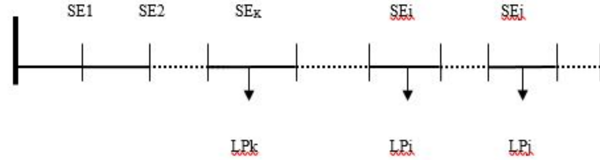

Figure 1: Sample Distribution System

A distribution feeder consists of a set of series components, including lines, cables, disconnects, etc. A customer connected to any load point of such a system requires a set of component between load and supply points to be operating. These sets are designated as "cut-sets". The reliability of load point. LPi be calculated using minimal cut- set technique [5]. In this method, all of the minimal cut-sets which interrupt power to load point LPi are identified.

$$\lambda LPi = \sum_{i=1}^{m} U_j \lambda_i; U_{LPi} = \sum_{i=1}^{m} U_j; r_{LPi} = \frac{U_{LPi}}{\lambda_{LPi}} \quad (1)$$

Where m is the number of contingencies in the network that cause interruption of supply in LPi; λ_j, r_j and U_j are the average failure rate, outage duration and annual unavailability of contingency j; λ_{LP}, r_{LPi} and U_{LPi} are the reliability indices of load point i with isolation devices. U_j is equal to λ_j r_j for the load points downstream of the failed section and λ_j t_{isol} for the load points upstream of the failed section. Performances are measured by means of these indices.

1. System Average Interruption Frequency Index (SAIFI)

$$SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i} f/Customer.yr \quad (2)$$

2. System Average Interruption Duration Index (SAIDI)

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i} hr/Customer.yr \quad (3)$$

3. Customer Average Interruption Duration Index (CAIDI)

$$CAIDI = \frac{\sum U_i N_i}{\sum \lambda_i N_i} hr/Customer.Interrupt \quad (4)$$

4. Average Service Availability Index (ASAI)

$$ASAI = \frac{\sum N_i \times 8760 - \sum U_i N_i}{N_i \times 8760} p.u. \quad (5)$$

5. Average service unavailability index (ASUI)

$$ASUI = \frac{\sum U_i N_i}{N_i \times 8760} p.u. \quad (6)$$

ASUI =1-ASAI Where 8760 is the number of hours in a calendar year.

6. Expected Energy not Served Index (EENS) It is the total energy not supplied by the system.

$$EENS = \sum Load \times OutageDuration$$
$$EENS = \sum_s L_s U_s \frac{kWh}{year} MWhr/Customer.yr \quad (7)$$

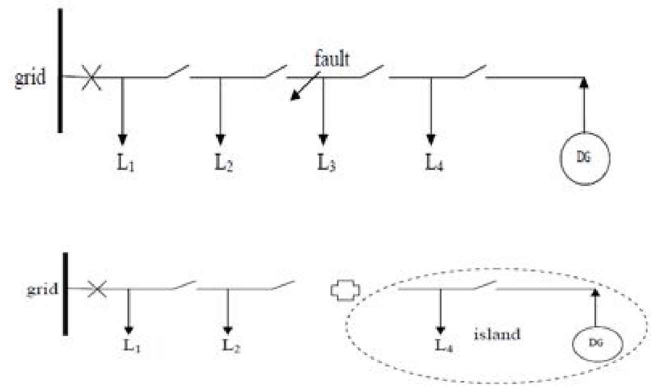

Figure 2: Process of islanding

2.5 Problem Formulation

Connection of DG in distribution systems would considerably improve system reliability through supplying loads in island, which is disconnected with substation during contingencies, until the utility can restore additional delivery capacity. This is shown in Figure 2. After a contingency on the feeder section between L2 and L3, an island composed of one DG and one load L4 is formed.

The following steps are involved for evaluating the reliability of the radial distribution feeder

1. Developing the model of distributed generation (DG)
2. Developing the reliability evaluation concept when several number of DGs are
3. Reliability parameters has calculated using ETAP Simulation methods without using DGs
4. Applying the developed DG model and reliability evaluation concept in ETAP Simulation to calculate the reliability parameters
5. Comparing the reliability parameters of radial distribution feeder with and without connection of DGs.

2.6 Method of Application

A distribution test system has 13 different sections having 112 load points. Six cases have been analyzed

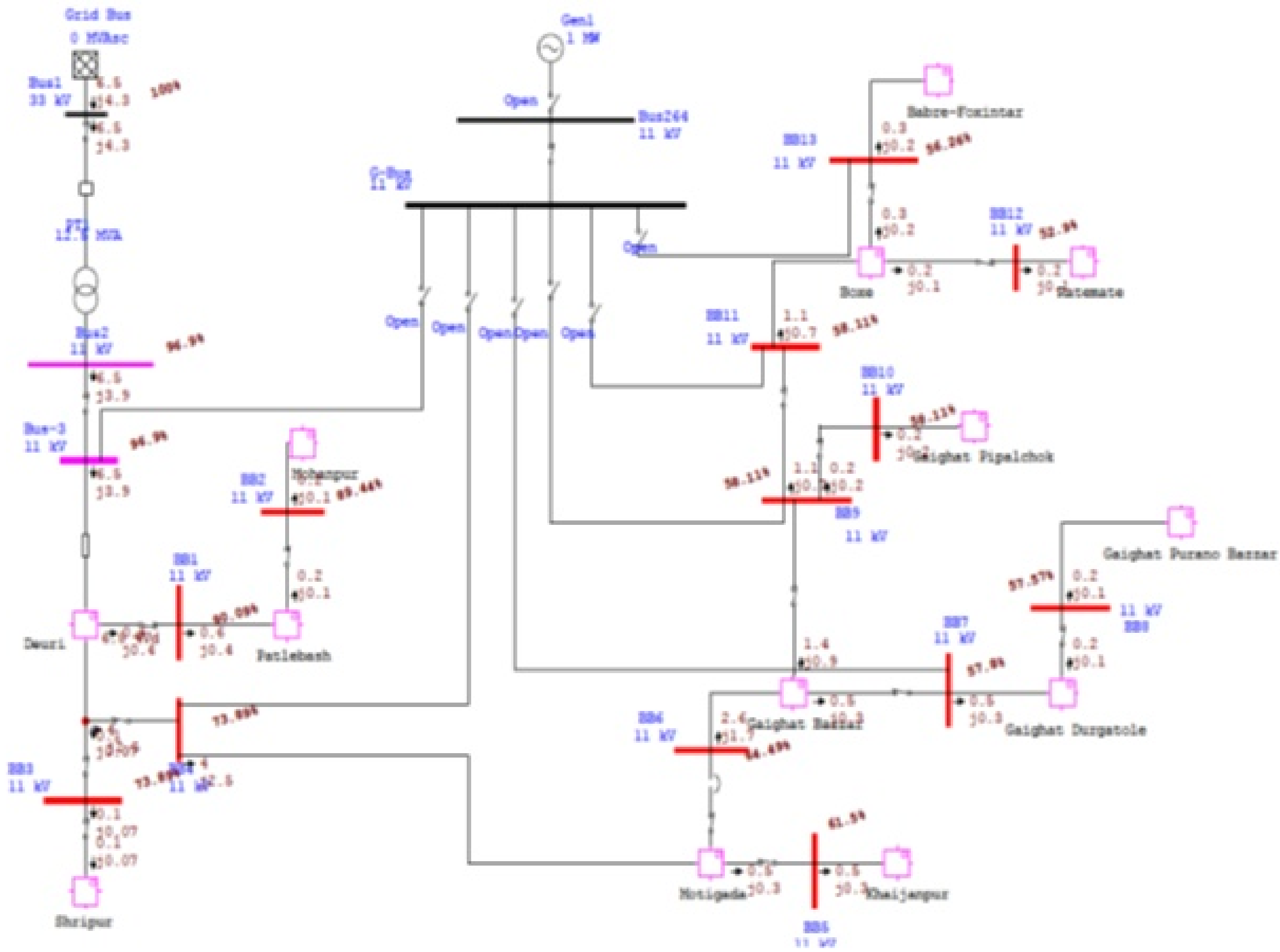

Figure 3: Simulation result showing failure rate and annual outage at different sections

for the analysis of the location of DG on the test feeder. In this case study, Distributed Generation (DG) acts as distribution substation, we mean that DG can alternatively supply to the load without capacity limitation. In the case of a DG conventional station, produces its nominal capacity, i.e. 1 MW for all time. DG is connected to different six sections of feeder in different cases. The reliability of the distribution test system is performed first without the DG and with DG on the test feeder.

Six cases are investigated on distribution test system; (1) without DG, (2) DG at 3.5 km near the substation section SE1, (3) DG at section SE4 i.e. 7.0 km far from substation, (4) DG at section SE7i.e. 9.9 km far from substation, (5) DG at section SE9 i.e. 9.0 km far from substation, (6) DG at section SE11 i.e.16.0 km far from substation and (7) DG at section SE13 i.e. 10.5 km far from substation. Reliability indices SAIFI, SAIDI, ASUI and EENS are measured with and without placement of DG. Table I shows failure rate and repair time of test feeder without DG and Table II shows results of reliability indices at different locations on distribution test system. The Reliability indices SAIFI, SAIDI, CAIDI, ASAI, ASUI, EENS obtained with and without placement of DG are shown in 1.

Figure 8 showed the calculated value of SAIFI for all cases. It can be observed that expect case 1 and case 2, the remains cases slightly changes in system reliability with the DG. The lowest value of SAIFI is in case 3. Figure 9 indicates that results for SAIDI, for each case. It is clear that SAIDI value is the lowest for Case-5 where DG is located at BB11, which is the farthest load

Table 1: Simulation result showing failure rate and annual outage at different sections

SE	Length (km)	Failure rate (f/yr)	Annual Outage time (hr/yr)	Number of Customer
Bus	7.3	0.65	1.588	17098
BB1	13.05	4.145	156.163	1229
BB2	23.1	5.769	213.957	858
BB3	5.6	4.325	153.763	427
BB4	9.6	4.325	161.443	1253
BB5	14.3	4.647	176.583	1795
BB6	4.4	9.441	332.744	1947
BB7	3.8	9.563	337.644	950
BB8	8.7	9.582	345.564	820
BB9	15	9.543	333.644	2913
BB10	2.6	9.545	337.584	849
BB11	12.4	9.545	338.544	2064
BB12	5.4	11.129	395.948	709

Table 2: Reliability indices with and without DG forvarious cases

Cases	SAIFI (f/cust.Yr)	SAIDI (hr/cust. Yr)	CAIDI (hr/cust.int.)	ASAI (p.u)	ASUI (p.u.)	EENS (MWh/Yr)
Case-0	7.7875	274.449	35.242	0.9687	0.03133	1511.484
Case-1	7.175	258.207	35.986	0.971	0.0294	1421.724
Case-2	6.964	256.458	36.824	0.971	0.0292	1412.08
Case-3	4.912	177.619	36.159	0.98	0.0202	972.159
Case-4	4.914	177.62	36.142	0.98	0.02026	972.171
Case-5	4.914	177.594	36.141	0.98	0.02026	972.03
Case-6	4.8984	177.462	36.228	0.98	0.02027	972.321

point from the 11 kV supply bus. When DG is moved from BB7 to BB3, the value of SAIDI increases. For case-1 is higher SAIDI, the reason being DG is near to the supply point.

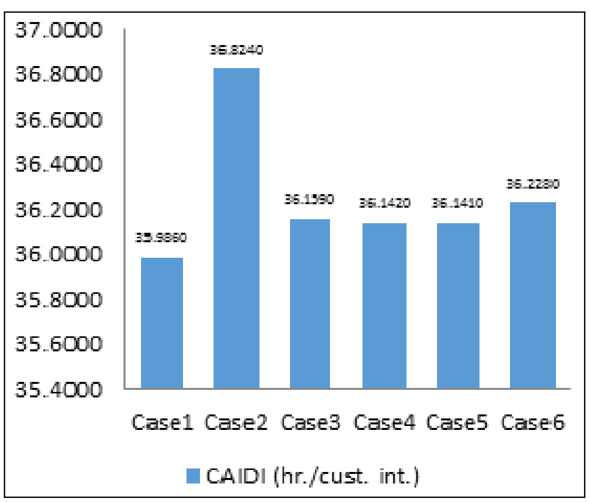

Figure 4: Graph for CAIDI

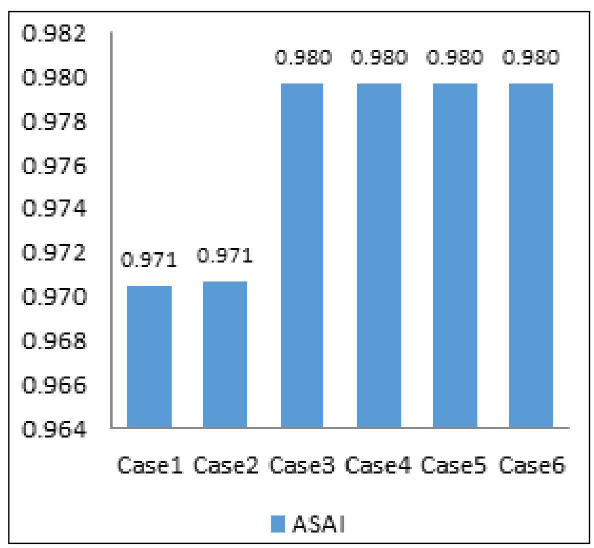

Figure 5: Graph for ASAI

Figure 4 represented the results for CAIDI for each case. The value of CAIDI is the highest for case 2as compared to case 1 where DG is connected to BB3. Figure 5 showed ASAI in all cases. The values of ASAI for the Case 3 to Case 6 are same. With the effect of DG on the distribution system, the value of ASAI is decreased from case-3 to case- 1.

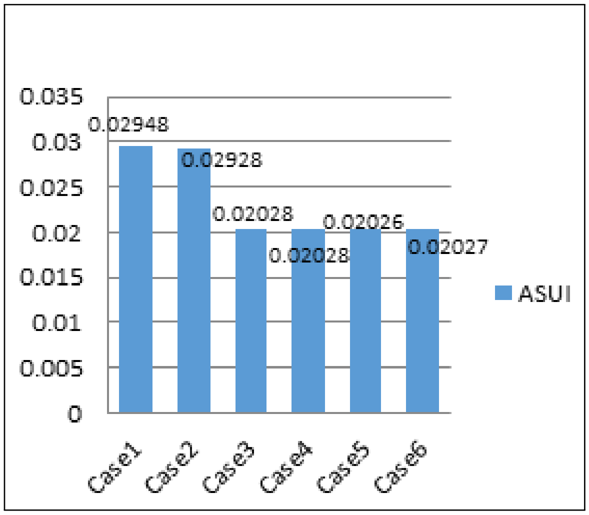

Figure 6: Graph of ASUI

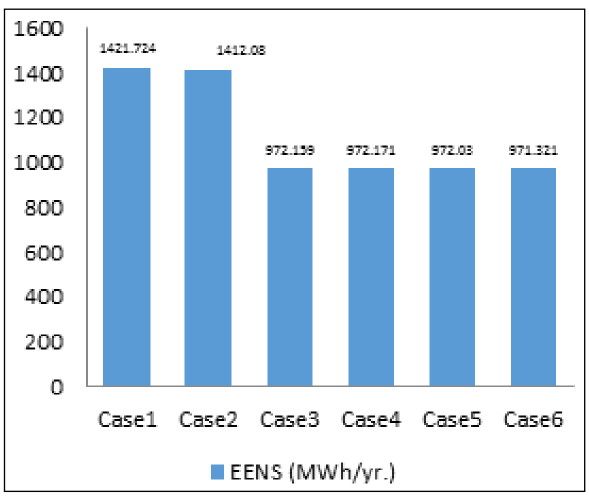

Figure 7: Graph of EENS

Figure 6 indicates that calculate the value of ASUI for all the cases. The value of ASUI is lowest at the case-5 as compared to the all other cases. Case 1 to give higher value, where the DG is connected to the Bus 3 closed to the substation. Figure 7 indicates that calculate the value of EENS for all the cases. The value of EENS is lowest at the Case-5 as compared to the all other cases. Case 1 gives higher value, when the DG is connected to the Bus 3.

2.7 Results and Discussion

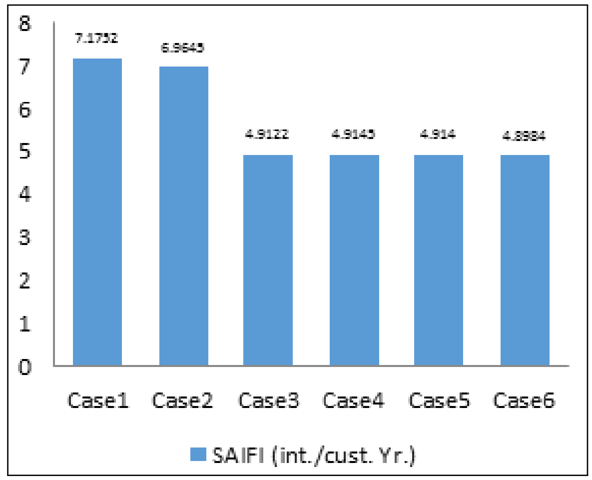

Figure 8: Graph of SAIFI

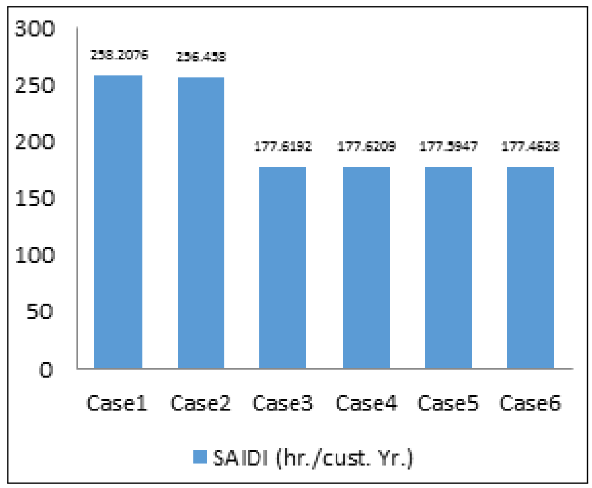

Figure 9: Graph of SAIDI

3. Conclusion

The results obtained from the analytical method gives reliability indices SAIFI, SAIDI, ASUI and EENS have achieved minimum and ASAI has maximum value in case 6 as compared with other cases whereas CAIDI has achieved minimum value in case 5. Therefore, an impact of DG on reliability is negligible, when the DG is placed near to the substation. The results showed the DG modeling is one of the factors in the distribution system reliability analysis. In addition to the results show that case-6 is the best location of DG in the Gaighat radial distribution feeder due to high load demand and more number of customers. The indices clearly show that reliability of the power system improves by injection of DG into distribution system more close to load points or far from supply source.

Acknowledgments

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